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Power Plant Design for Gas Power

Mechanical Engineering

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POWER PLANT DESIGN FOR GAS POWER

BY

HOMER ROBERTS LINN

B. S. University of Illinois, 1896

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MECHANICAL ENGINEER

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

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May 1, 1909

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

HOMER ROBERTS LINN, B.S., 1896

ENTITLED POWER PLANT DESIGN FOR GAS POWER

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF MECHANICAL ENGINEER

In Charge of Major Work

L. P. Breckenridge

Head of Department

Recommendation concurred in:

W. F. M. Goss
A. N. Talbot

Committee on Final Examination

145233

POWER PLANT DESIGN FOR GAS POWER

BY

HOMER ROBERTS LINN, B.S. '96.

THESIS

FOR THE DEGREE OF MECHANICAL ENGINEER

IN THE

GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS.

PRESENTED MARCH 27, 1909.

SUMMARY.

HISTORY.

In preparing a thesis on an internal combustion engine power plant it is interesting as well as profitable to briefly review the history of the development of the gas engine. The first attempt at producing an internal combustion engine was in the 18th century, by an inventor who utilized the explosive effect of gun-powder, but no further steps were taken until about 1826, when Browne brought out his gas vacuum engine in England.

About 1880 the French engineer Lenoir produced an engine in France, and in 1862 Hugon, another French engineer, produced an engine which met with no better success than that of Lenoir. These were low compression engines, and of very low efficiency.

In 1862 Beau de Rochas, another French engineer, developed an engine which was far superior in its theoretical design than any of its predecessors. This engine was of the four-cycle type and has been slowly developed by various engineers, until at present it is the leading type of internal combustion engine.

FUNDAMENTAL THEORY.

The fundamental theory of internal combustion engines was discovered by Beau de Rochas, and explained in these words, "The rapidity of action in both combustion and expansion is the basis of success in explosive motors". It is not our purpose to go into the thermodynamics of the gas engine, as this subject is fully treated in a number of scientific works.

However, we will mention a few of the underlying principles especially adapted to the gas engine. When air, gas, or the vapors of gasoline or petroleum oil are heated they change

their pressure in nearly the same ratio. When they are combined chemically by what is commonly known as burning, or what is termed the explosion in the gas engine, the pressure due to this combustion is very high. The natural laws which treat of the expansion and compression of gases by work and by heat have been expounded by Boyle and Gay-Lussac.

LAW OF BOYLE:-

The law of Boyle is stated in these words, "If the temperature of a gas be kept constant its pressure or elastic force will vary inversely as its volume".

LAW OF GAY-LUSSAC:-

The law of Gay-Lussac is stated in these words, "A gas expands by heat and contracts by loss of heat, the change in its volume causing a free piston to move in the cylinder 1/492 part of its volume for each degree Farenheit when taken at 32° F.

EXPLOSIVE MIXTURES:-

In regard to the explosive effect of the mixtures of gas and air, there is a limit to the relative proportion that is explosive, depending upon the amount of combustible in the gas. With ordinary coal gas and air, one part of gas and fifteen parts of air are non-explosive. If the mixture is enriched so that we have one volume of gas to two volumes of air, it is also non-explosive. Between these proportions we will obtain explosions varying in effect, the most intense pressures being obtained from a mixture of approximately one part of gas to six parts of air.

GAS ENGINE FUELS.

A great many different kinds and forms of fuels have been used to generate power in internal combustion engines. However, they may be generally classified under the three heads, solid fuel, liquid fuel and gaseous fuel. In order to obtain the best results from the fuel used it must mix easily with the air in the cylinder of the engine and must not ignite too easily when the charge is compressed in the cylinder. The amount of compression which may be carried in any particular engine is largely governed by the amount of hydrogen present in the fuel. The most common fuels used in internal combustion engines to-day are gasoline, kerosene, crude oil, natural gas, coal or illuminating gas, producer gas and blast furnace gas.

Gasoline has the formula C_2H_{14} and varies in specific gravity from .70 to .74 by the Baume Scale. The flashing point of gasoline ranges from 10° to 14° F.

Kerosene has a specific gravity from .78 to .82 and a flashing point of 120° to 125° F. Its heating value varies slightly from 22,000 B.T.U. per pound.

Crude oil is a varying product as found in the different parts of the United States. It has a variable flashing point and heating value, although an average heating value is somewhere near 20,000 B.T.U. per pound.

Natural gas varies in its constituents and heating value in the different gas fields, the gas from the eastern fields being higher in B.T.U. per cu. ft. than that from the western

fields. Natural gas in the Pittsburg district has approximately the following make-up:

Hydrogen (per cent)	22.00 (by volume)
Marsh-gas	67.00
Ethane	5.00
Heavy hydrocarbons	1.00
Carbonic oxide	00.60
Carbonic acid	00.60
Nitrogen	3.00
Oxygen	.80
	100.00
B.T.U. cu. ft.	900.00

The coal or illuminating gas as produced in Chicago has a heat value of approximately 650 B.T.U. per cubic foot.

The constituents in producer gas vary considerably, due to the manner of generating the gas. A good grade of producer gas should show a high percentage of carbon monoxide and a rather low percentage of hydrogen. The following is a fair analysis of a sample of producer gas:

Carbon monoxide	30.00% (by volume)
Hydrogen	7.00
Marsh-gas	1.50
Carbon dioxide	1.50
Nitrogen	60.00
	100.00

The yield of gas from one ton of good anthracite pea coal should be approximately 170,000 cu. ft. of gas. This gas should have an average heating value of 135 B.T.U. per cu. ft.

Blast furnace gas has an average composition of

Carbon monoxide	26.5%
Carbon dioxide	11.5%
Hydrogen	3.3%
Marsh-gas, a trace	
Nitrogen	58.6%
	99.9%

The heating value of a mixture may be calculated from the heat values and percentages of the substances of which it is composed. It may also be found by direct determination in a calorimeter.

For example, CO_2 is composed of 12 parts of carbon to 32 parts of oxygen, by weight. Therefore to burn one pound of carbon requires 32/12 pounds of oxygen or 2,2/3 pounds. If the oxygen is taken from the air it will require 2,2/3 divided by.23 equals 11.6 lbs. of air, which will be necessary to supply the 2,2/3 lbs. of oxygen required for complete combustion. The reason why so much air has to be supplied is because there is only 23% of oxygen by weight in the air, the remainder being principally nitrogen. The weight of the products of combustion found in burning 1 lb. of carbon will be 1 lb. carbon + 2.67 lbs. oxygen= 3.67 lbs. CO_2. The 8.93 lbs. of nitrogen passes off as a useless gas.

To burn 1 lb. of carbon to CO will require only one-half as much air as to burn the same carbon to CO_2. Consequently, it would require only 5.8 lbs. of air which would supply to the carbon 1.334 lbs. of oxygen, so that the weights of the products of combustion would be CO = 2.334, and nitrogen=4.466 lbs.

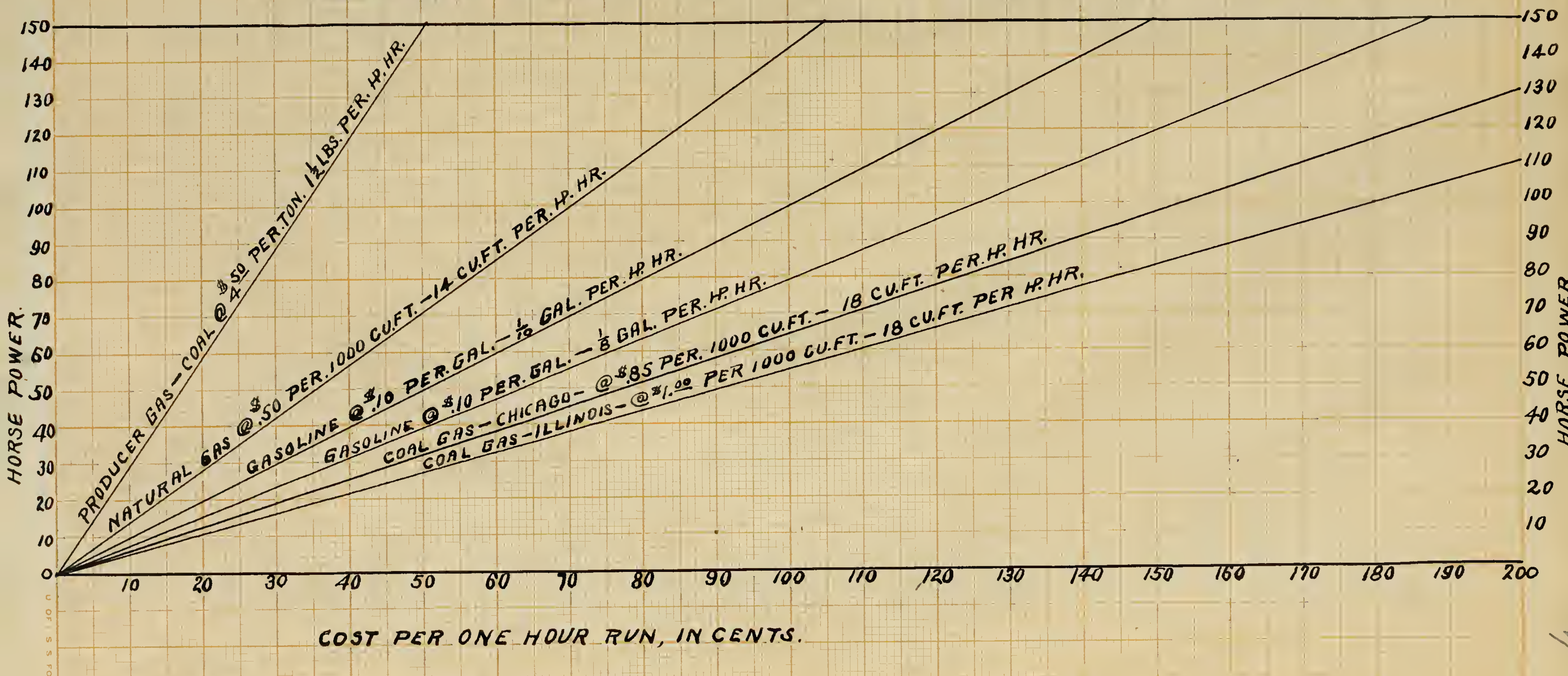
To convert 1 lb. of CO into CO_2 would require $5.8 \div 2.33 = 2.48$ lbs. of air.

The quantity of heat obtained by complete combustion of the various gases and elements has been found by experiment. We give below some of the heat values as found by Berthelot.

One lb.	B.T.U.
H	62100
C to CO2	14647
C " CO	4480
CO	4383
Methane	24017
Ethylene	21898
Acetylene	21856

From this it will be seen that the amount of air required for complete combustion of any particular gas depends upon the combustible in the gas. That is, when the percentages of the different constituents of a gas are known, the amount of air required can be determined. From experiments we have made we have found that it is very essential to have the correct proportion of air in the mixture in the cylinder at the time of the explosion, if the gas or vapors of gasoline or petroleum are thoroughly mixed with the air. However, we recently made some experiments on a two cycle gasoline engine where the gasoline was injected under pressure and did not thoroughly mix with the air in the cylinder. These experiments proved that the efficiency of the engine was not materially changed when there was more air introduced under this condition than was needed for complete combustion. We were also able to run with much less cooling water than usual.

Comparative Cost Of Power With Different Gas Engine Fuels.



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SOME POINTS FOR EFFICIENT OPERATION.

There are so many variables which have to do with the efficiency of an internal combustion engine that it is hard to say which of these are the most important. It would make our thesis too tedious to take up each of these in detail. However, we wish to discuss three or four.

JACKET WATER:-

A great many experiments have been made both in this country and in Europe to determine the exact effect of the jacket cooling water on the efficiency. A French engineer has recently made tests in which he found that a saving of 7% in gas consumption per brake H.P. hour was made by raising the temperature of the jacket cooling water from 140° to 165° F. We made some experiments a few years ago on a 25 H.P. single cylinder four-cycle engine and found that we effected a saving of 10% by raising the temperature of the jacket water from 60° to 145° F. We carried this temperature to as high as 200° F. without any serious effect on the working parts of the engine, and thereby increased the saving in gas consumption 19.7% over cooling water at 60° F. It is very difficult to say the exact temperature at which cooling water should be run for different size engines, as it varies largely with the size and design, but it can easily be determined for any particular engine. We have found that the installation of thermostatic control valves on the jacket water outlet decreases the fuel consumption materially.

COMPRESSION:-

One of the important things necessary to obtain the power and economy in a gas engine is the amount of compression carried by the engine. The degree of compression has had a growth from 0 lbs. in the early engines to the present high compression engines. It has been found that the pressure immediately after the explosion in a gas or gasoline engine is approximately three to four times the pressure prior to ignition. It might be thought on account of this that the compression could be raised to an indefinite amount. However, it is not practical to compress the gases above certain well defined limits. With gasoline vapor and air the compression cannot be safely raised above 85 lbs. gauge to the square inch, and it will be found that more regular explosions will be obtained by not raising this pressure to over 75 lbs.

For natural gas of about 900 B.T.U. the compression pressure may be from 110 lbs. to 130 lbs., while with producer or Blast Furnace gas the compression pressure may be from 150 lbs. to 200 lbs. With crude oil the compression pressure may be from 250 to 300 lbs.

SPEED:-

The speed of the engine plays no small part in its efficiency. In an experimental investigation of a gas engine under variable piston speeds it was found that the useful effect increases with the velocity of the piston, that is, the more rapid the expansion of the burning gases, the greater the efficiency obtained. It was found that an engine running on a

mixture of one volume of gas to $6\frac{1}{2}$ volumes of air, with a piston speed of 5.5 ft. per second, was three times as efficient as when the piston speed was increased to 14 ft. per second. (Hiscox)

IGNITION:-

The means of firing the charges in explosive motors has developed from the open flame and slide valve type of the earlier engines to the hot tube and electric ignition of the present types. The successful operation of the explosive motor depends very much upon the perfection of the ignition mechanism. The hot tube ignition gave very fair results when the tubes were renewed at short intervals, but if the tubes were allowed to run very long at a time, they became oxidized and did not readily fire the charge. It will also be seen that with hot tube ignition the time of igniting is largely dependent on the temperature of tube and the degree of compression, so that the hotter the tube or the higher the compression, the earlier the ignition.

The different electrical devices are many and varied but there are two general types, the jump spark and the make and break. With the jump spark an induction coil is employed, the points of the igniter remaining at a constant distance apart, the time of the spark being controlled by external contact points. In the make and break igniters the points are mechanically separated, either by external or internal means. With either of the electric devices the time of ignition may be changed to different points of the stroke without regard to the amount of compression carried by the engine.

The time of ignition is a very important factor in the economical operation of the gas engine. Different authorities vary considerably as to the proper time of igniting the charge, but it is not uncommon to find engines igniting 25° ahead of center. Engines using gas of low hydrogen sometimes are fired 40° ahead of center.

It seems to us that the time is at hand for engine builders to adopt a system of ignition on all engines where the point of ignition may be advanced or retarded while the engine is in operation.

AIR INLET:-

The size of the air inlet is a subject which is receiving careful attention at the present time. Recently we have made a number of experiments along this line, and found that in some makes of engines we were able to effect a saving by decreasing the air inlet, the gas inlet remaining the same, while in others it was necessary to increase the air inlet. It would seem at present that it would be quite desirable to have an air inlet, the area of which could be readily changed.

REGULATION GUARANTEES:-

The regulation of gas engines is as yet very poor compared to that of the steam engine, water wheel, or steam turbine. We sometimes read in catalogs that "Our engine is the only one on the market that will run an electric light plant successfully". Such a statement as this is without meaning, and a guarantee based on such an assertion is absolutely worthless. Our attention was called not along ago to one maker who claimed that

his engine would regulate within 1% of normal between 50% load and full load. Another maker says he is willing to guarantee his engines of 100 H.P. to successfully operate alternators in parallel, but when such guarantees are given we may be assured that the maker has left some loop hole through which he can escape the penalties.

The guarantees of fuel consumption made by some makers are just as radical as those of regulation. For instance, one maker will guarantee his engine to develop an indicated H.P. on a certain number of cubic feet of city gas. As an illustration of this, one maker guarantees to deliver an indicated H.P. on 17 cu. ft. of coal gas, or 15 cu. ft. of natural gas. This kind of a guarantee is very unsatisfactory from the point of view of the ordinary operator of gas engines. The guarantee on fuel consumption should be based on British thermal units per brake H.P. These are quantities which can be definitely determined, and over which no dispute is liable to arise.

GAS PRODUCERS & PRODUCER GAS.

HISTORY:-

Recent developments indicate very positively that two factors will be of great importance in the economical production of power for manufacturing and transportation purposes. These two factors are the replacing to a marked extent of the steam boiler and steam engine by producer gas plants, with their accompanying internal combustion engines and the centralization of power production and distribution. In view of the possibility of the gas producer and gas engine displacing the steam engine, the U.S. Government made special provisions for producer gas tests at its fuel testing plant installed in connection with the Exposition at St. Louis. These tests have furnished valuable data on the relative consumption of coal per H.P. hour when used by a steam plant and by a gas plant.

The credit of being the first to design a practical gas producer belongs undoubtedly to MM. Thomas and Laurent, who between 1838 and 1841 constructed a gas generating furnace in which many improvements were anticipated. Air from a blower was admitted from the bottom of the furnace and the decomposition of the air was assisted by the injection of superheated steam. There are a number of distinguished engineers who must also be mentioned in connection with the early history of producer gas generators. The first pressure generators were introduced by Dowson of London, and while he installed a great many of these producers they were of a very complicated nature. However, these complications have

been overcome largely by later designs. For a long time the name Dowson was almost synonymous with producer gas. His producers were of such design as to necessitate the use of anthracite coal or coke.

Bénier and A. Taylor, two French engineers, made some very praiseworthy, although not immediately successful attempts to simplify the manufacture of producer gas. Along with the name of Dowson that of Dr. Mond must be mentioned as being one who took an active part in the vigorous development of further forms of producers. While Dowson worked along the line of an anthracite coal producer, Dr. Mond worked along the line of a bituminous coal producer.

The name Siemens is also connected with the early history of the producer and it was he who developed the regenerative furnaces in 1857, such as were employed in the process of steel making.

The rapid advance of the large gas engine has been made possible by improvements in the production of cheap gas directly from fuel through the aid of the gas producer. An early form of producer introduced in Europe and now in very general use both abroad and at home, is known as the suction producer. It received this name from the fact that the engine develops its charge of gas in the producer by means of its own suction stroke. As far as known, the first suction producer operated in the United States was installed in 1903, although producers of other

types were tried in this country as early as 1896.

The general requirement of a gas engine fuel is that it must readily mix with air to form a combustible air or vapor. It must also burn with little or no residue. The latter requirement is not met by the solid fuels such as powdered coal for instance. A great many unsuccessful attempts have been made to use powdered coal, but the ash residue soon seriously interferes with the operation of the engine. For this reason the necessity of having a gas producer which would simply and economically convert solid combustible matter into a gaseous state has been strongly responsible for the development of the suction gas producer.

A serious limitation to the utility of the suction producer has been the fact that owing to the manner of generating the gas, no tarry fuels could be used. This prevented the use of bituminous coal, lignites, peats and other light fuels. The fuels in most common use for producers of this kind, are charcoal, coke and anthracite coal. However, there is good reason to believe that with the experiments going on at the present time, we may shortly expect a suction producer which can be operated successfully on bituminous coal. In the pressure producer the gas is generated under slight pressure, due to the introduction of an air and steam blast, and stored in a holder until it is required for the engine. As the gas may thus be stored before passing to the engine, and as it is produced under pressure, tar and other impurities may be removed from it by devices that permit

the use of bituminous coal and lignites.

DISCUSSION OF PRINCIPLES.

The various points to consider in discussing the subject of producers can best be understood by a description of the operation involved.

A fire is built on the grate at the bottom of the producer, until we have a depth corresponding to the depth of our producer, all the time air is blown through openings in the grate, up through the mass of fuel; this may be accomplished by means of a blower, or by a suction exhauster, or the fuel may be raised to incandescence by means of a natural draught, but whatever the means employed, the object aimed at is the same, the only difference would be the amount of gas produced in a given time, and naturally the greater amount of air, the greater the volume of gas produced, with its attendant rapid increase in temperature. Take for example a fuel of anthracite or coke, the product from either fuel if steam is passed up through the grate, will be composed of carbonic acid, carbon monoxide, hydrogen and nitrogen.

Having our fuel raised to a reasonably high temperature throughout its mass, we now begin the manufacture of producer gas by passing air only through the grate in the bottom of the producer. The first reaction that takes place, if air alone is used, either by suction or under pressure, by blowing in, is as follows; Air is composed of 23 parts of oxygen and 77 parts nitrogen by weight; nitrogen is inert, does not burn and does not assist combustion, in fact is useless; oxygen is a supporter

of combustion. As the air comes in contact with the hot fuel the oxygen of the air combines with the carbon of the fuel and burns to form carbonic acid gas thus; $C + 2O = CO_2$. The nitrogen of the atmosphere simply retards combustion and tends to smother the fire.

As the carbonic acid gas mixed with inert nitrogen passes up through the mass of hot fuel, it is decomposed into carbon monoxide thus $CO_2 + C = 2CO$.

Our first product, carbonic acid, is not combustible, but by decomposing it into carbon monoxide, we obtain a combustible product. If steam is passed into the producer then our product will be composed of hydrogen in addition to the above gases; in fact water, in the form of steam aids the decomposition of the previously formed carbonic acid; water is composed of the elements hydrogen and oxygen. Hydrogen is combustible and will burn. The following equation shows how water is decomposed in contact with incandescent carbon: $H_2O + C = CO + 2H$.

By this it will be seen that producer gas consists of useful as well as inert substances. Take for instance, the combustible ingredients found in producer gas, which is made from coke or anthracite. In this gas will be found carbon monoxide, hydrogen and nitrogen, while in addition to these if bituminous coal is used, we would have compounds of carbon and hydrogen known as carbureted hydrogen or marsh gas, and some traces of heavy hydro-carbons, the proportion depending on the composition

of the coal and the method and temperature at which the producer was run. With bituminous coals the higher the temperature the greater will be the volume of lighter hydro-carbon gases produced. Here we come in contact with one of the difficulties in the production of producer gas from soft coal. The tar and heavy hydrocarbons pass off and condense in the outlet pipes. They eventually leave a thick deposit of pitch, which combining with the dust and soot carried over from the producer, complete a mixture which in time causes the pipe to become stopped up. Many devices have been invented to overcome this trouble, but there is one general principle which must be carried out, and the sooner it is carried out the greater is the success, that is, the heavy tarry compounds must be decomposed. This can only be done by submitting them to a high temperature before leaving the producer. In suction producers a great deal of trouble is encountered by fusing the ash when the temperature is raised high enough to decompose these tarry compounds.

ESSENTIAL POINTS TO CONSIDER.

There are several important points to consider in the successful operation of a producer and we wish to mention some at this time, especially in connection with the suction producer.

LOCATION IN THE PLANT:-

The gas generator should be so placed, where possible, that it is easily accessible from all sides. With a producer thus located the operator can easily stoke the fire and leave it in a uniform condition. Operators often make the mistake of stoking unevenly and too often, especially where they can get at the fire

from but two sides of the producer. Uneven stoking, either from the sides or from the top, in a producer which is working up to, or near its capacity, is very liable to cause fusing of the ash. This in time will scaffold from the sides of the generator until it is completely closed up.

AIR SUPPLY:-

Another important point is to see that there is a thorough and equal distribution of air through the masses of coal so as to prevent it burning in holes. This is accomplished by many varied forms of grate, each manufacturer generally having this part of his generator patented. In some producers the water seal is used and the steam from the hot ashes keeps the grate cool and renders the clinkers soft and pliable.

STEAM SUPPLY:-

The steam is usually supplied from a vaporizer or boiler which is heated by means of the hot gases just as they leave the generator on their way to the scrubber. It is very important that this steam supply be so arranged as to be under the control of the operator. The steam is usually generated under no pressure, and in many of the installations the means of regulating the height of the water is a simple overflow box located conveniently near the generator, so that it is at all times in sight of the operator.

STARTING THE PRODUCER:-

Where producers are used in intermittent service, such for example, as day load in industrial or manufacturing plants, it is necessary to bring the generator up to a producing state in the morning before starting the engine. It is well to do this

by means of a suction exhauster instead of by a pressure blower, as in this case the exhauster puts on the producer the same kind of service required by the engine and delivers the gases through an exhaust pipe to the outside air. With the pressure blower which is sometimes used there is a liability of the gases leaking into the engine room. We have known a number of cases where this has been the cause of sickness and loss of life, of persons employed in the engine room, as the CO gas is quite poisonous. All ash and cinders should be removed from the generator before the exhauster is started.

YIELD OF GAS:-

Regarding the yield of gas, it must be remembered that it is impossible for a gas producer to create either heat or matter. It simply changes the form of matter but does not increase or create any more power than was originally present in the coal. For example, if one pound of anthracite coal contains 14,000 heat units, it is impossible to get 14,001 heat units from this coal by means of a producer. The yield of gas is based on the grade of coal and the heat units per cubic foot of gas. For example, it makes no difference in the yield of gas if one producer will produce 80 cu. ft. of gas per pound of coal, while another will produce only 40 cu. ft. of gas, both using the same grade of coal, provided the gas from the second producer contains twice as many heat units per cubic foot, as that of the first producer, although it might make a difference in the value of the producer to do a certain work.

BLAST FURNACE GAS ENGINE PLANT AT GARY, IND.

Power engineers have been very much divided in their opinions as to the reliability of internal combustion engines to give continuous service. Although there has recently been a number of comparatively large sized units installed both in this country and in Europe, yet it was not until the United States Steel Co. made their most modern plant almost entirely dependent upon internal combustion engines for its power, that the whole world began to realize the reliability of gas engines. We made an inspection of this blast furnace gas engine plant at the Indiana Steel Co., Gary, Ind., in order to give here a short description of it.

The complete installation consists of three houses, two for the blowing engines and one for the electric power plant. The electric power plant contains 17 twin tandem, double acting, four-cycle gas engines. Fifteen of these are direct connected to 2000 K.W., three phase, 25 cycle alternators. Two of them are direct connected to 2000 K.W., 250 volt D.C. generators. Each of the engines occupy a floor space of approximately 43 x 70 ft., and weigh approximately 1,750,000 lbs. each. The cylinders of the electric engines are 44" in diameter by 54" stroke. The piston speed when the engines are running normal, is approximately 750 ft. per minute, the rim velocity of the fly-wheel being approximately 6000 ft. per minute.

FOUNDATIONS:-

Owing to the fact that the plant is built on sand it has been necessary to put very heavy foundations under the buildings and machinery. Excavations were made in the sand to a depth corresponding with the water level of Lake Michigan, then a solid slab of concrete 6 ft. thick was put under the entire building. The walls of the building and the foundations for the engines rest on this slab, no piling at all being used.

GAS:-

The gas is generated in the blast furnaces, from there it passes to the primary washers, which are composed of vertical cylinders having spiral baffle plates. The gas enters at the top of the primary washer, passing out near the bottom. From here it goes to the Choppy Washer. This washer is filled with wooden grids, the gas passing upward through these grids against a spray of water. From here it goes to the Thiessen Washers. These washers are rotated by means of direct connected motors. The gas passes through the washer and passing out at the top goes directly to the gas holders. The gas holders are weighted for 5½" pressure. The gas in the holder has but .0065 grains of impurity per cubic foot, which is cleaner than the ordinary air. For every cubic foot of air which is blown into the furnace 1½ cu. ft. of gas is given off. About 70% of all the gas generated is saved. Of this, 65% is available for gas engines, the rest being used in the furnaces, stoves, etc. The average composition of the gas is

CO	26.5
CO_2	11.5
H	3.3
CH_4	.1

The rest is made up of nitrogen and moisture. This gas has a heating value of 95 to 105 B.T.U. per cubic foot, and as it comes to the engine has approximately 3.3 grains of moisture per cubic foot.

ENGINES:-

They have found that the mixture best suited for their engines is one part of gas to one part of air. The engines are designed to carry 200# compression when running at normal load, and will develop their rated capacity on gas of 77 B.T.U. per cubic foot. They are also designed strong enough to carry an overload equal to that obtained from gas of 110 B.T.U. per cubic foot. The generators are rated at 2000 K.W. and are 35° machines. They are designed to carry a 50% overload continuously.

The blowing engines operate Slick blowing tubs which have a capacity of 33,000 cu. ft. of free air per minute per engine. The pressure carried on the air mains by these blowing tubs is from 15 to 30# per sq. in. The cylinders of the gas engines operating these blowing tubs are 42 x 54" and are rated at 54 revolutions per minute, however, they have successfully operated these at 70 R.P.M. The jacket cooling water is brought in from the Lake through a tunnel half a mile long. They have experienced considerable trouble from fish getting into the cooling water jackets and stopping circulation, and have found it necessary to install twin strainers to catch these fish. The engines are lubricated by means of a gravity circulating oil system, the oil

being stored in tanks in the basement. It is pumped into a reservoir high enough to give a pressure of about 15# per sq. in. on the system at the engines. The system holds approximately 25,000 gallons of oil and is purified by means of precipitation and settling tanks.

SPECIFICATIONS FOR SUCTION GAS PRODUCER PLANT.

These specifications are to cover all labor and material necessary to install a complete 150 H.P. plant to be operated on producer gas. The building, sewers, catch basins and floor will be furnished by the building contractor, but this contractor is to furnish and install the gas producer, cleaning apparatus, holder, engine, coal conveying machinery, piping and starting apparatus complete.

This contractor will take the building as he finds it, do all his own cutting, remove the debris resulting from his work, and turn the plant over to the owner in successful operating condition.

The payments on the contracts will be as follows; on machinery, one-third of the contract price will be paid upon delivery of the apparatus at the building, one-third upon erection and one-third after 30 days successful operation. On labor, payments will be made from time to time up to 85% of the Engineer's estimate of the work done. The balance will be paid in full upon successful completion of the work.

All work is to be carried on in a workmanlike manner and in such a way as to cause no labor troubles with any of the trades employed on the installation.

The plans attached to and made a part of these specifications are not detail and are intended to show relative locations and positions. No changes in locations will be permitted unless

written permission is obtained from the Engineer in charge. Details necessary for the successful operation of the plant, whether shown or not, will be included in this contract. At the time of signing the contract the successful bidder must submit such detail plans of the apparatus he proposes to install, as the Engineer may request.

PATENTS:-

Contractor will indemnify the purchaser against any and all losses which the latter may sustain through suits or otherwise on account of using any patented article furnished under this specification, or under any extra that may be allowed hereafter.

Contractor further agrees to defend any suits for infringement of patent in such a manner as to cause minimum inconvenience to the purchaser.

APPROVED:-

Where materials are specified by brand or maker's name, bidders will have the privilege of submitting other brands for approval. No substitutions will be permitted, however, in carrying out the contract unless such substitute materials have previously been approved in writing by the purchaser's Engineer, and it is understood that such materials, if used, are to be removed by the contractor without expense to the purchaser, and replaced by the material specified.

INSPECTION:-

All labor and material furnished under these specifications are to be at all times subject to the inspection of the purchaser's Engineer and must be approved by him in writing before final payment is made.

SUCTION GAS PRODUCER.

The producer shall consist of a generator, economizer and vaporizer, scrubber and holder, and all necessary connections.

TYPE:-

The gas producer will be of the suction type and will be capable of furnishing 15,000 cu. ft. of gas per hour continuously, having a minimum heating value of 125 B.T.U. per cubic foot.

GENERATOR:-

The generator will consist of a steel shell lined with fire brick, fitted with a circular grate. It must be installed in such a manner as to be capable of being rotated to a limited extent by a lever attachment to the outside of the shell. The grate will also be supported in such a manner as to be easily removed without breaking the brick lining. The top of the generator is to be water jacketed and the water from this jacket is to be carried to the vaporizer and economizer. The top of the generator is also to be fitted with a hopper into which the fuel is charged. The hopper is to be so arranged that the connection between the generator and hopper is closed when the hopper is being filled. This charging arrangement is to be so arranged that no air will enter the generator when the coal is discharged into the magazine. The outlet for the gas from the generator to the economizer is to be near the top of the generator, and the opening into this pipe is to be protected in such a manner that the coal will not choke it.

FUEL:-

The producer shall be so designed that it will successfully operate on commercial pea anthracite coal of 12,000 B.T.U. per pound.

SCRUBBER:-

The shell of the scrubber will be made of steel boiler plate not less than 3/8" in thickness, the heads to be of 3/8" steel. The joints between the head and the shell are to be caulked so as to be tight when tested under 10 lbs. of air pressure. There will be provided two manholes and manhole covers to permit of the removal of the coke. The coke is to rest on four cast iron grates supported by angle irons. The first will be placed at least 16" from the bottom of the scrubber and the others four and eight feet respectively above the first. The coke is to have a depth of 120" and is to be wet on the top by means of a water spray consisting of three nozzles, made of 1/2" pipe capped and having ten 1/8" holes drilled in each. The supply of water to these nozzles will be controlled from a valve placed in the water pipe outside of the shell of the scrubber within easy reach of the operator. The scrubber will be provided with an overflow which will drain to catch basin. This contractor will make all water connections as well as drains to catch basin.

ECONOMIZER:-

The economizer and vaporizer will be located between the producer and the scrubber and will be of such dimensions as to furnish 1.2 lbs. of steam for each pound of coal burned. The economizer will be of such construction that the incoming air for supporting the combustion shall pass through the economizer

and be heated by the hot gases which also generate the steam. The amount of vapor passing into the bottom of the generator will be controlled by a control valve within easy access of the operator.

HOLDER:-

After the gases have passed through the scrubber they will be carried into a vertical holder by a pipe entering from the top, which shall project downward to within 18" of the bottom of the holder. The suction pipe to the engine will be taken from the top of this holder. The capacity of the holder will be equal to at least one-third the cubic capacity of the scrubber. The holder will have a 3" water sealed drain to sewer.

SUCTION EXHAUSTER:-

Contractor will install a suction exhauster in the gas line leading from the holder to the engine, as shown on plan. It will be so installed that it will deliver the exhausted gas from the producer to the outside air, and must be so valved as to close completely when the engine is in operation.

DATA:-

Contractor will furnish the following data pertaining to the producer which he proposes to furnish.

Diameter of generator.
Height of generator.
Size of grate in generator.
Height of fuel above grate.
Capacity of hopper.
Diameter of scrubber.
Height of scrubber.

GAS ENGINE.

TYPE:-

The engine will be of the four-cycle type, having four cylinders. It shall be capable of developing 150 actual brake H.P. at the sheave wheel when operating on producer gas of 125 B.T.U.

GENERAL:-

The engine will be of the vertical self-contained, enclosed type. The body of the frame shall form an enclosed case which contains the crank shaft, main bearings, (except outboard bearings), connecting rods and brasses. It shall be oil tight and shall be so arranged that the lubricating of the main bearings, connecting rod bearings and gears shall be accomplished by means of a splash oil system. The lubrication of the cylinders will be accomplished by means of a mechanical forced feed lubricator. Cast iron cover plates will be securely bolted to the frame on each side so as to allow easy access to the brasses.

The cylinders will be securely bolted to the cast iron frame. They are to be of selected close grained charcoal iron. They are to be water jacketed and the water manifolds shall be so arranged as to allow for expansion and contraction without causing leakage of the water supply. There will be installed in the water outlet of the jacket water a thermostatic control valve which will be so adjusted as to keep the temperature of the exhaust water practically constant.

VALVES:-

The inlet and exhaust valves will be made of steel forgings and will be so arranged as to be easily removed for grinding. The valve seats shall be of cast iron and are to be so

water jacketed as to keep them reasonably cool.

BEARINGS:-

The five main and two outboard bearings will be lined with copper hardened babbitt metal. They will be provided with adjustable take-up blocks. The inside bearings are to be so designed that the oil splashed by the splash pins in the crank brass bolts will properly lubricate them. The outboard bearings will be ring oiling.

CRANK SHAFT:-

The crank shaft will be in one piece of forged Open Hearth steel. It will be finished all over.

CONNECTING RODS:-

The connecting rods are to be of forged Open Hearth steel finsihed all over and bearings are to be of phosphor bronze.

SPEED:-

The speed will be 275 R.P.M.

GOVERNOR:-

The governor will be of the throttling type and will be adjusted so as to maintain a speed regulation within 2% from no load to full load, when the load is gradually applied.

FLY-WHEELS:-

There will be two fly-wheels 76" in diameter. They will be properly fitted and keyed to the crank shaft. The right hand one, as shown on plan, will be a machine finished sheave wheel having 12 grooves of proper shape to take 1,1/8" hemp rope. The left hand wheel will have crowned face.

IGNITION:-

The engine is to be equipped with electric igniters of the make and break type, with platinum points. The external arrangement is to be such that the time of ignition may be changed while running. Current for the igniters will be furnished by a Bosch magneto. There will also be furnished a set of twelve large size dry cells connected four in series, the three series connected in multiple.

COOLING TANK:-

The contractor is to furnish and install a cooling water tank of not less than 3000 gallons capacity, the water to be supplied to this tank through an automatic float valve and circulation to be insured by means of a rotor pump installed in the line to the cylinders. This pump will be installed with a valved by-pass.

STARTING DEVICE:-

There is to be furnished a compressed air starting device consisting of an air compressor belted to a 10 H.P. vertical gasoline engine running at a speed of 300 R.P.M. The compressor must have automatic unloading device, and must be capable of filling the tanks with air at 150 lbs. gage pressure in 30 minutes. The compressed air is to be stored in three tanks of not less than 20 cu. ft. each and are to be so arranged that any one or all of the tanks can be used at one time.

FOUNDATION TEMPLATE, ETC.:-

This contractor will furnish a foundation template, bolts, anchors and bolt sleeves.

OPERATOR:-

The contractor shall furnish, without cost to the purchaser, a competent operator for a period of ten consecutive days after the plant has been turned over to the purchaser, to instruct the purchaser's engineer.

SHAFTING, PULLEYS & BELTS:-

The shafting for the coal elevator leg will be 1,15/16" cold rolled steel. The hangers will be cast iron inverted hangers with adjustable ring oiled bearings, and will be supported from the steel roof trusses on substantial frame work installed by this contractor. All belts, except the rope drive to the mill, will be oak tanned light double and will be furnished and installed by this contractor.

GUARANTEE:-

Contractor will guarantee all apparatus furnished under this contract to be free from all inherent defects and will replace free of charge any part failing on account of workmanship or material, within one year after the acceptance of the plant.

TESTS:-

The purchaser shall have the right to run such tests for thirty days after the plant is turned over by the contractor, as he may deem necessary to ascertain whether all contracts have been properly fulfilled. At the expiration of thirty days successful operation and the proper fulfillment of all contracts, the purchaser shall give to the contractor a letter of acceptance. Final payment shall then be made in full.

DATA:-

Contractor will include the following data in his bid:

Size of cylinders.
Compression in lbs. at sea level at full load.
Size of main bearings.
Size of connecting rod bearings.
Weight of fly-wheel.
Weight of sheave wheel.
Total weight of engine.
Floor space of engine.
Guaranteed delivery of all apparatus.
Guaranteed date of completion of entire installation.
Lbs. coal required to operate engine at (full load / half load / no load

MISCELLANEOUS SPECIFICATIONS.

PIPING.

All pipe and fittings will be of standard weight and only new material is to be used. All water piping is to be run with due allowance for drainage. All pipe must be well supported by substantial hangers. The joints are to be made tight without the use of white or red lead.

GAS PIPING:-

The gas piping will be run as shown on drawing. There will be two pipes passing through the roof to the outside air, one to be taken off at the by-pass valve between the economizer and scrubber and to be so arranged that when the producer is temporarily shut down, with the fire going, the gas produced will pass out through this pipe to the air. The other pipe will be the discharge from the suction exhauster. The exhaust from the engine will be carried through the side of the building and then upward. It will end just above the roof and must be securely fastened by 1/2" round iron bands securely bolted to the building wall. The bottom elbow will have a 3/4" drain cock. All gas piping will have flanged fittings, and blank flange Tees must be so placed that the gas piping can be readily cleaned.

VALVES:-

The valves in the water and air lines will be brass rough body Jenkins disk and will have nickel trimmings and wood wheels. The valves in the gas lines will be iron body, brass trimmed flanged gate valves.

All water and air connections will be made of galvanized pipe.

COVERING.

This contractor will cover all cold water piping with 1" of hair felt covering. This covering is to be protected by canvas jacket. That portion of the exhaust piping which is between the engine and the point where the pipe passes out of the engine room will be covered with 1" Vitribestos covering held in place by metal bands.

COAL CONVEYING MACHINERY.

This contractor will furnish and install one bucket elevator, one receiving hopper and one coal bunker.

RECEIVING HOPPER:-

The receiving hopper will be made of 3/8" boiler plate securely riveted together, 3'-6" wide by 5'-0" long by 3'-6" high. It will have a sloping bottom so that the coal will discharge by gravity into the receiving boot. One side of this hopper will be hinged so that it will open outward through an opening provided in the wall. This will act as a receiving shoot for unloading the coal from the wagon. This receiving hopper is to be securely fastened to the wall by means of a 2 x 3/8" iron band passing around the top edge of the hopper and bolted to the wall with two 3/4" bolts. It will also be supported by substantial floor supports.

COAL BUNKER:-

Contractor will install a coal bunker at such a height that the coal will discharge by gravity into the hopper of the

producer. This bunker will be 7 ft. wide by 10 ft. long by 4 ft. deep and will be made of 3/8" boiler plate securely riveted together. This coal bunker will be supported on 10", 25# "I" beams one end of which is imbedded in the wall, the other end being supported by a $1\frac{1}{4}$" rod suspended from the roof truss. The side of the bunker next to the producer will be supported on a 4 x 4 x 3/8" angle iron securely riveted to the side of the bunker and resting on the 10" "I" beam. The discharge spout into the hopper of the producer will have a closing valve installed in it.

ELEVATOR LEG:-

This contractor will furnish an approved type of elevator leg having 4 x 6" steel elevator buckets carried on sprocket chains. These buckets are to be spaced approximately 24" apart. The boot is to be made of #10 steel, the head to be of #14 steel and will have three doors conveniently placed in the casing, one to be near the bottom, one near the middle and one near the top. The driving pulley will be in the head and the take-up in the boot. The drive will be from a line shaft and the drive pulleys will be tight and loose, but the belt shifter will be so arranged as to be operated from the floor by means of chains extending down the side of the elevator leg.

FOUNDATIONS.

All foundations will be located as shown on drawing, and must be laid out by center lines. The foundations will be built of concrete in the proportions of 1-3-5. The broken stone must pass through a 1½" ring and rest on a 1/2" ring.

The cement and sand are to be thoroughly mixed dry, the stone is then to be added and thoroughly mixed. The concrete must be thoroughly tamped with a tamper weighing at least one pound per square inch of tamping face. The dimensions of the foundations are shown on drawing, but the final dimensions must be approved in writing after the contracts for machinery have been let and template drawings of apparatus have been approved by the Engineer.

All parts of the foundations which show above the floor or around the bases of the machines must be finished with a smooth coat of cement, applied while the foundation is still wet.

PAINTING.

All machinery will have two coats of metallic filler applied before shipment, this filler to be rubbed down to a smooth finish. After the machinery is erected it will be thoroughly cleaned with gasoline and then painted as follows:

The shell of the producer and the economizer will be painted with a black metallic paint suitable to stand high temperatures. The scrubber, holder and cooling water tank are to be painted with a black enamel paint suitable to withstand moisture.

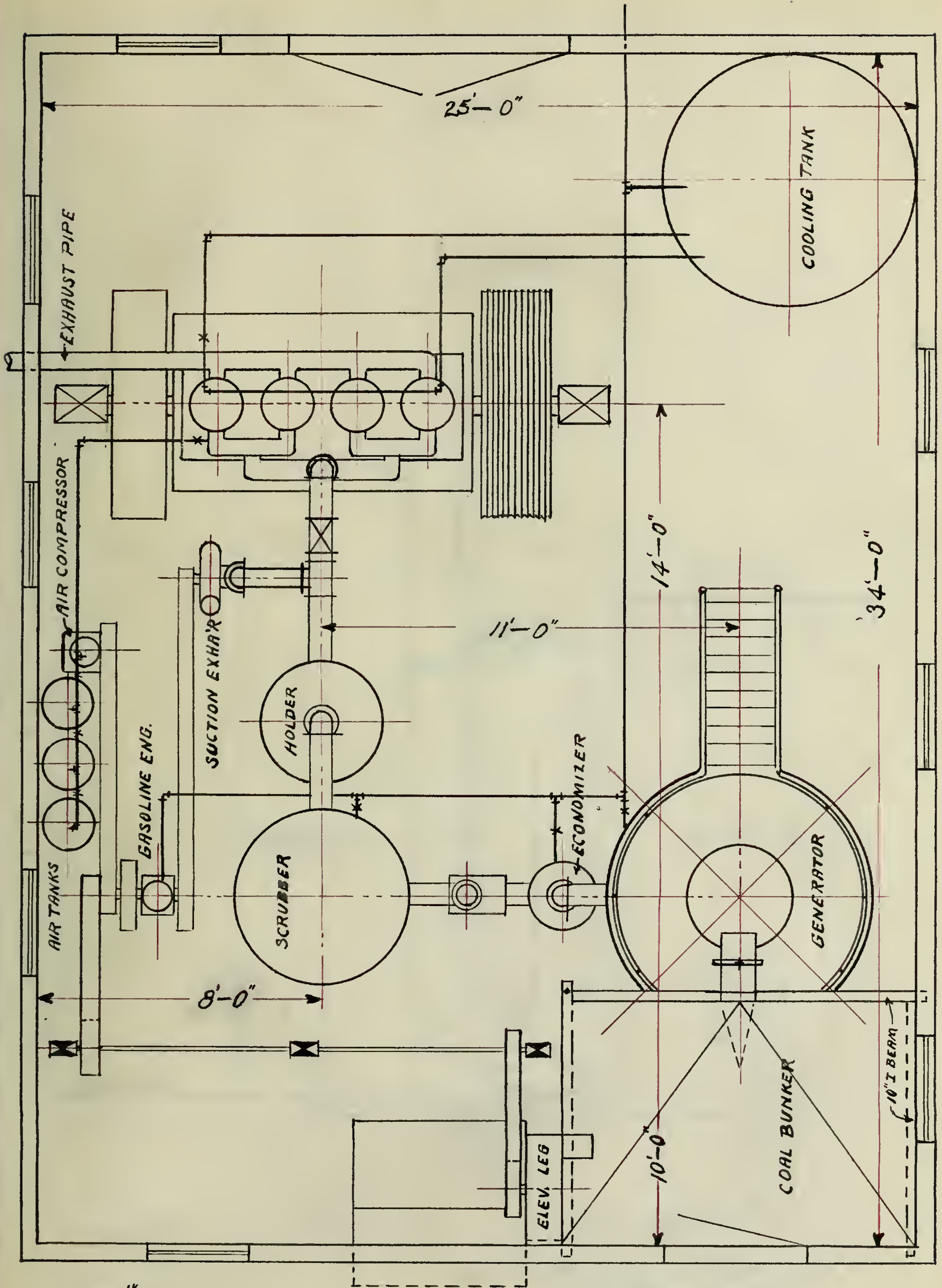
The engine will be painted with two coats of flat maroon

color and then have two coats of hard drying varnish, at least twenty-four hours to be allowed between the application of the different coats so as to be sure that the former is thoroughly dry.

All piping and pipe covering, also the coal bunker, elevator leg and receiving hopper will be painted with a black elastic metallic paint.

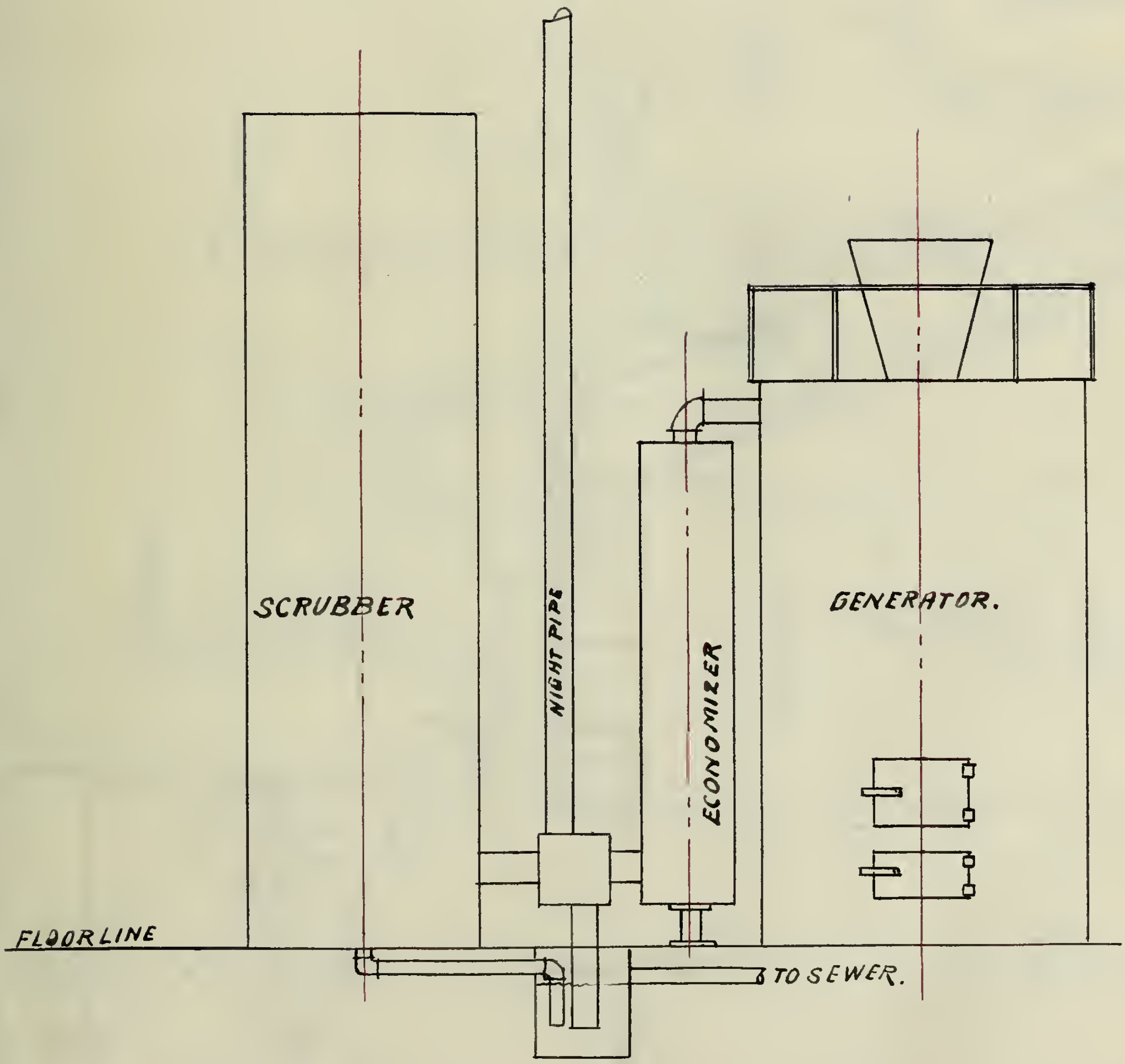
The small gasoline engine, air compressor, suction exhauster and air tanks are to be painted with a maroon metallic flat color and given two coats of varnish.

All valves will be painted with a maroon enamel.



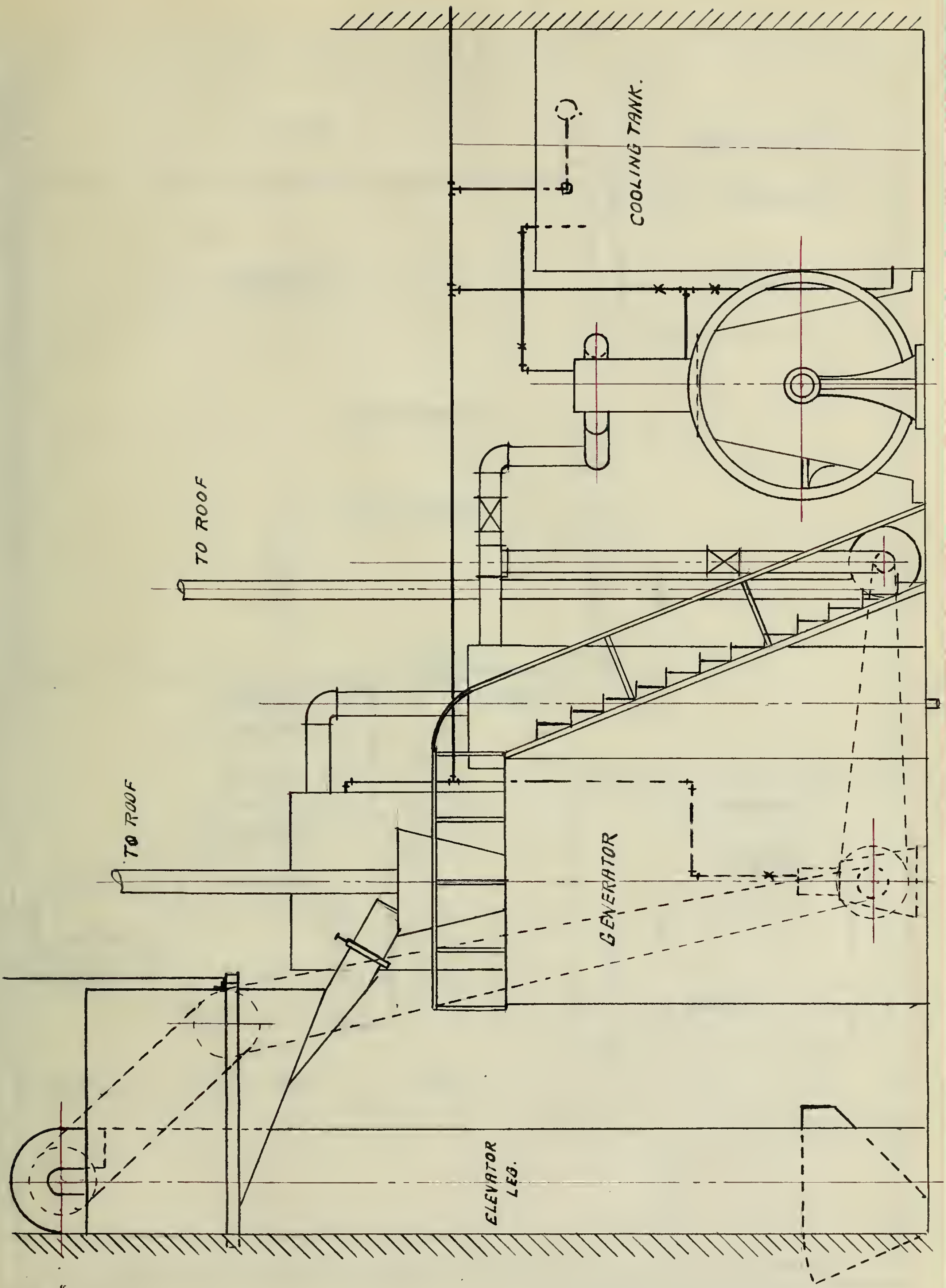
Scale $\frac{1}{4}$" = 1'

GENERAL PLAN.



Scale $\frac{1}{4}$" = 1'

ELEVATION
GENERATOR, ECONOMIZER,
AND
SCRUBBER



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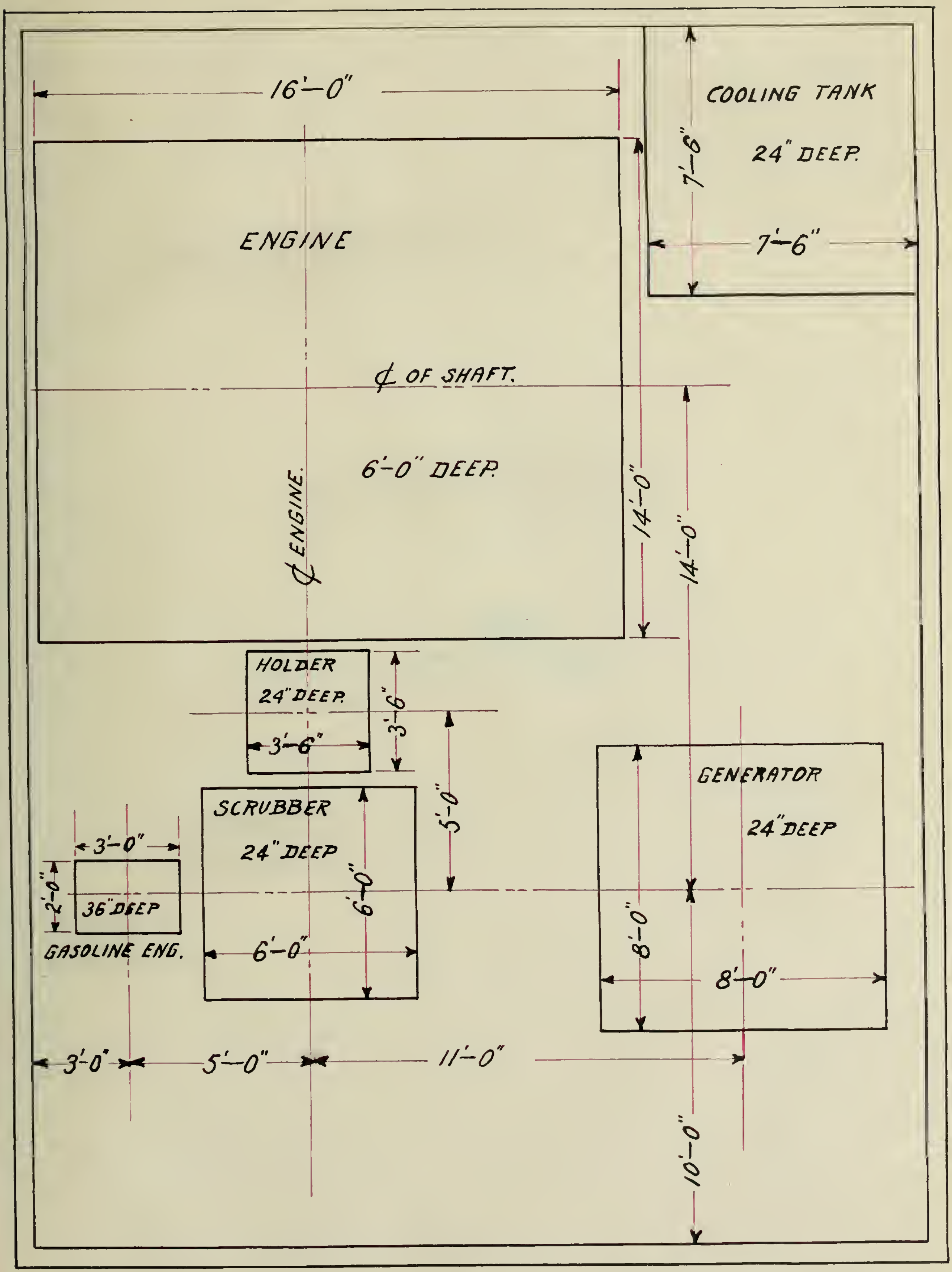
GENERAL ELEVATION.



Scale 1/4" = 1'

FOUNDATION PLAN.

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